Magnetospheric Particles and Earth

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The History
Van Allen Belts
Van Allen radiation belts

A. Gyro

B. Bouncing

C. Longitudinal drift
Coordinate systems

**Geographical coordinates:**
- Latitude ($\phi$)
- Longitude ($\lambda$)
- Altitude ($h$)

**McIlwain coordinates:** $L, B$
- $L = \frac{r_{eq}}{r_{Earth}}$
- $B$ – geomagnetic field induction;

**Geomagnetic coordinates:**
- Longitude ($\lambda$)
- $L = \frac{1}{\cos^2(\phi_m)}$
- $\phi_m$ – geomagnetic latitude
- $r_{eq} = r_{Earth} + h$
Periods of longitudinal drift of electrons and protons in radiation belt (for L=1.2)
Connection between latitude and L-coordinate for low-altitude orbits (400 – 600 km)
Early Space Missions
Electron and Proton flux variations below the radiation belts

- Electron  Intercosmos Bulgaria-1300 and Meteor 3
- Mariya  Salyut 7
- Mariya-2  MIR
- Gamma 1  GAMMA Astrophysical Station
- Meteor 3A
- Oreol 3
Magnetic time of flight spectrometer
Mariya (Mariya-2)

Spectrometer registers charged particles (20-200 MeV) separately: electrons, positrons, protons, antiprotons et. al., measures their energy and incident angles. Instrument consists of plastic scintillation hodoscope, permanent magnet and time of flight system.
Single and Multiple Electron Bursts

![Graphs showing single and multiple electron burst activity](image-url)
Duration distributions for high-energy electrons bursts (experimental data)
L-distribution for earthquakes

MARIYA-2

GAMMA-1

the number of bursts

L-shell

the number of bursts

L-shell

the number, a.u.

L-shell

earthquake distribution
Ionospheric-magnetosferic perturbation

EME

- Natural emissions (earthquakes and volcanic eruptions)
- Anthropogenic emissions (PLHR, VLF & HF transmitters)

ULF EME wave-trapped particle interaction?
Ground-based preseismic EME observations

Loma Prieta earthquake, October 18, 1989, M=7.1

Spitak earthquake, December 7, 1988, M = 6.9
ULF and LF seismic origin electromagnetic noises.

1. Observation of ULF emission on the surface of the Earth (1989, Loma-Prieto, M=7.9). 3 hours before earthquake (0.05 – 0.2 Hz).

2. Observation in the space:

20.01.1989: Particle burst was registered in two hours and ten minutes before earthquake.
Wave – particles interaction mechanism

Schematic representation in a meridian plane of the trapped particle trajectories

1. EARTHQUAKE PREPARATION AREA

2. EM WAVES PROPAGATION INTO THE IONOMAGNETOSPHERE

3. EM WAVES GENERATE PERTURBATIONS IN THE LOWER IONOSPHERE

4. EM WAVES INTERACT WITH CHARGED TRAPPED PARTICLES IN THE INNER RADIATION BELT

5. PARTICLE PITCH ANGLE CHANGES ↓
   MIRROR POINTS LOWERING ↓
   PARTICLE PRECIPITATION

6. PBs PROPAGATE AROUND THE EARTH ALONG THE L-SHELL ↓
   (LONGITUDINAL DRIFT)
   PBs DETECTABILITY AT ANY LONGITUDE

Stationary lower boundary of the radiation belt

Mirror points lowering

PBs

Stationary trajectory of trapped particles

Geomagnetic field lines
\[ \Delta L = (L_{EQ} - L_{PB}) \leq 0.1 \]

\[ H_{mirror} \approx 300 \text{ km} \]

\[ \Delta T = T_{EQ} - T_{PB} \]
Correlations between EQ & ps: $\Delta T_{EQ-PB}$ distributions

**MIR** mission
1985-2000
Altitude: 400 km
Inclination: 51°
$E_e: 20 \div 200$ MeV
$E_p: 20 \div 200$ MeV

**METEOR-3** mission
1985-1986
Altitude: 1250 km
Inclination: 82°
$E_e: \leq 30$ MeV

**GAMMA-1** mission
1990-1992
Altitude: 350 km
Inclination: 51°
$E_e: > 50$ MeV
SAMPEX-PET Mission

| Orbit altitude: | 520–670 km |
| Orbit inclination: | 82° |
| PET Pointing modes: | ORR; MORR; 1 RPM (see text) |

PET channel Level-2 data used for this study

<table>
<thead>
<tr>
<th>Particles</th>
<th>Energy (MeV)</th>
<th>Geometric factor ($m^2sr$)</th>
<th>Channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>28–60</td>
<td>1.5</td>
<td>PHI</td>
</tr>
<tr>
<td>Protons</td>
<td>19–28</td>
<td>1.65</td>
<td>PLE</td>
</tr>
<tr>
<td>Electrons</td>
<td>2–6</td>
<td>1.65</td>
<td>ELO</td>
</tr>
<tr>
<td>Electrons</td>
<td>4–15</td>
<td>1.5</td>
<td>EHI</td>
</tr>
<tr>
<td>Electrons</td>
<td>4–30</td>
<td>-</td>
<td>EWG</td>
</tr>
<tr>
<td>Protons</td>
<td>&gt; 60</td>
<td>0.4</td>
<td>RNG</td>
</tr>
<tr>
<td>Electrons</td>
<td>&gt; 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protons</td>
<td>&gt; 85</td>
<td>0.25</td>
<td>PEN</td>
</tr>
<tr>
<td>Electrons</td>
<td>&gt; 30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SAMPEX Pointing Modes

SAMPEX/PET has operated with three different pointing programs:

• ORR  (original Orbit Rate Rotation)
• MORR  (Modified Orbit Rate Rotation)
• 1 RPM  (1 Rotation Per Minute)

✓ During the ORR pointing mode the PET yaw axis is substantially radial to the Earth. So, PET may detect particles with pitch angle in a wide range and, in particular, also in the loss cone (precipitating particles) or near to it.

✓ On the contrary, in the MORR mode the detector yaw axis is fundamentally perpendicular to the geomagnetic field lines, since it was implemented mainly to study particles with pitch angle near 90° (trapped particles). Measurements for $\alpha_{PET}$ values far from 90° are performed in periods during which PET yaw axis is parallel to the geomagnetic field (B), when $B > 0.3 \, G$, and perpendicular to it, when $B < 0.3 \, G$.

✓ Finally, in the 1 RPM mode the $\alpha_{PET}$ distribution is flat since the PET yaw axis, rotating continuously at 1 RPM, allows the particle detection at any pitch angle value.
$\Delta T$ distribution of events (particle bursts and earthquakes). $\Delta T = T_{\text{earthq}} - T_{\text{burst}}$.  
Experimental data of PET/SAMPEX

Event selection:

1) $|\Delta L| < 0.05$

2) Magnitude of earthquakes $M > 5.0$

No correlation is obtained (that is, no relevant peak is observed) with PBEHI data collected in the other MORR(1), 1RPM, and MORR(2) pointing periods.

No correlation is obtained in the 4 pointing mode periods with PBEL0 data.
Correlations between EQ & ps: $\Delta T_{EQ-PB}$ distributions

**MIR mission**  
1985-2000  
Altitude: 400 km  
Inclination: 51°  
$E_e: 20 \div 200$ MeV  
$E_p: 20 \div 200$ MeV

**METEOR-3 mission**  
1985-1986  
Altitude: 1250 km  
Inclination: 82°  
$E_e: \leq 30$ MeV

**GAMMA-1 mission**  
1990-1992  
Altitude: 350km  
Inclination: 51°  
$E_e: > 50$ MeV

**SAMPEX/PET Mission 1992-1999**  
Altitude: 520\(\div 740\) km  
Inclination: 82°  
$4 \leq E_e \leq 15$ MeV

(Orbit Rate Rotation; July 1992 - May 1994)
Phase A Report
Italian Space Agency Program for Small Scientific Missions
July 2001

ESPERIA

Earthquake investigation by Satellite and Physics of the Environment Related to the Ionosphere and Atmosphere

Vittorio Sgrigna  Piergiorgio Picozza  Livio Conti
ESPERIA project

Electric probes A
FLUX-GATE
Zenith
PDA
LP&RPA
SEARCH-COIL
Electric probes B
ENEIDE mission
15-25 April 2005
Roberto Vittori

Esperia
Geo-magnetometer for a Low-frequency wave Experiment
The Resurs DK1 and VSPLESK ERA AGILE?
ARINA (Resurs-DK1 satellite, inclination 71°, altitude 350-600 km, from 2006)

VSPLESK (ISS, inclination 51.6°, altitude 300-350 km, from 2006)
On the basis of multilayer scintillation detector. Acceptance of ARINA 10-50 times higher than acceptance of instruments, used in earlier experiments for similar studies.

<table>
<thead>
<tr>
<th></th>
<th>Acceptance</th>
<th>10 sm(^2)sr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture</td>
<td>±30 degrees</td>
<td></td>
</tr>
<tr>
<td>Energy range</td>
<td>protons</td>
<td>30 – 100 MeV</td>
</tr>
<tr>
<td></td>
<td>electrons</td>
<td>3 – 30 MeV</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>protons</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>electrons</td>
<td>15%</td>
</tr>
<tr>
<td>Time resolution</td>
<td></td>
<td>100 ns</td>
</tr>
<tr>
<td>Mass</td>
<td></td>
<td>8,6 kg</td>
</tr>
<tr>
<td>Power consumption</td>
<td></td>
<td>13,5 W</td>
</tr>
</tbody>
</table>
ARINA and VSPLESK experiment.
Experimental data examples for particle bursts
ΔT distributions of events for various satellite experiments. $ΔT = (T_{\text{quake}} - T_{\text{burst}})$, $ΔL < 0.1$, $ΔL = |L_{\text{quake}} - L_{\text{burst}}|$
The Distribution Map of Seismic Belts

On each day there are about two earthquakes with magnitude $M > 5$.
Every two days there is a $M > 6$ earthquake.
ARINA observation of event 13.06.2006. 
particle burst (4:20); earthquake M=5.0 (6:30)

- At this moment, it's possible to use the following way for using particle bursts for remote diagnostics of local magnetospheric and geophysical events, including seismic. If the spectrometer on the satellite registered a electron burst, it is possible to determine the location (latitude) of the local perturbation of the radiation belts, which should be at the same L-shell that the place of particle burst registration. In case of a seismic disturbance that occurred during the earthquake preparation, it possible to determine the latitude of forthcoming earthquake. If there is a difference in the time of registration between groups of particle bursts with different energies, then by analyzing of the time structure and energy spectra of particles detected during the burst can provide additional constraints on the longitude of the location of possible disturbance source of the radiation belt, that is, longitude of the upcoming earthquake. The figure below illustrates this approach.

S.V. Aleksandrin, A.V. Bakaldin, A.M. Galper et al. 
Izvestiya RAN, 2009, 73, 379.
ARINA observation of event 29.05.2012.
Particle burst (06:05:00 UTC); earthquakes M from 4.3 to 5.5 (first 08:15:09 UTC)
ARINA observation of event 05.06.2006
particle burst (18:57); chemical explosion
(dust lightning) in Nevada, USA (18:53)
Simultaneous observation of electron bursts on ISS (red) and Resurs-DK1 satellite (blue)
Conclusions

• PBs of precipitating high-energy Van Allen electrons appear to precede statistically by some hours the occurrence of moderate and strong EQs.

• No correlation was found between PBs and other non-seismic sources.

Indication for a deeper investigation of the physical mechanisms under study.
The Next Future

- LIMADOU- CSES
- CHINA SEISMO-ELECTROMAGNETIC SATELLITE

- Talk R. Battiston
Thanks!

http://spaceweather.roma2.infn.it